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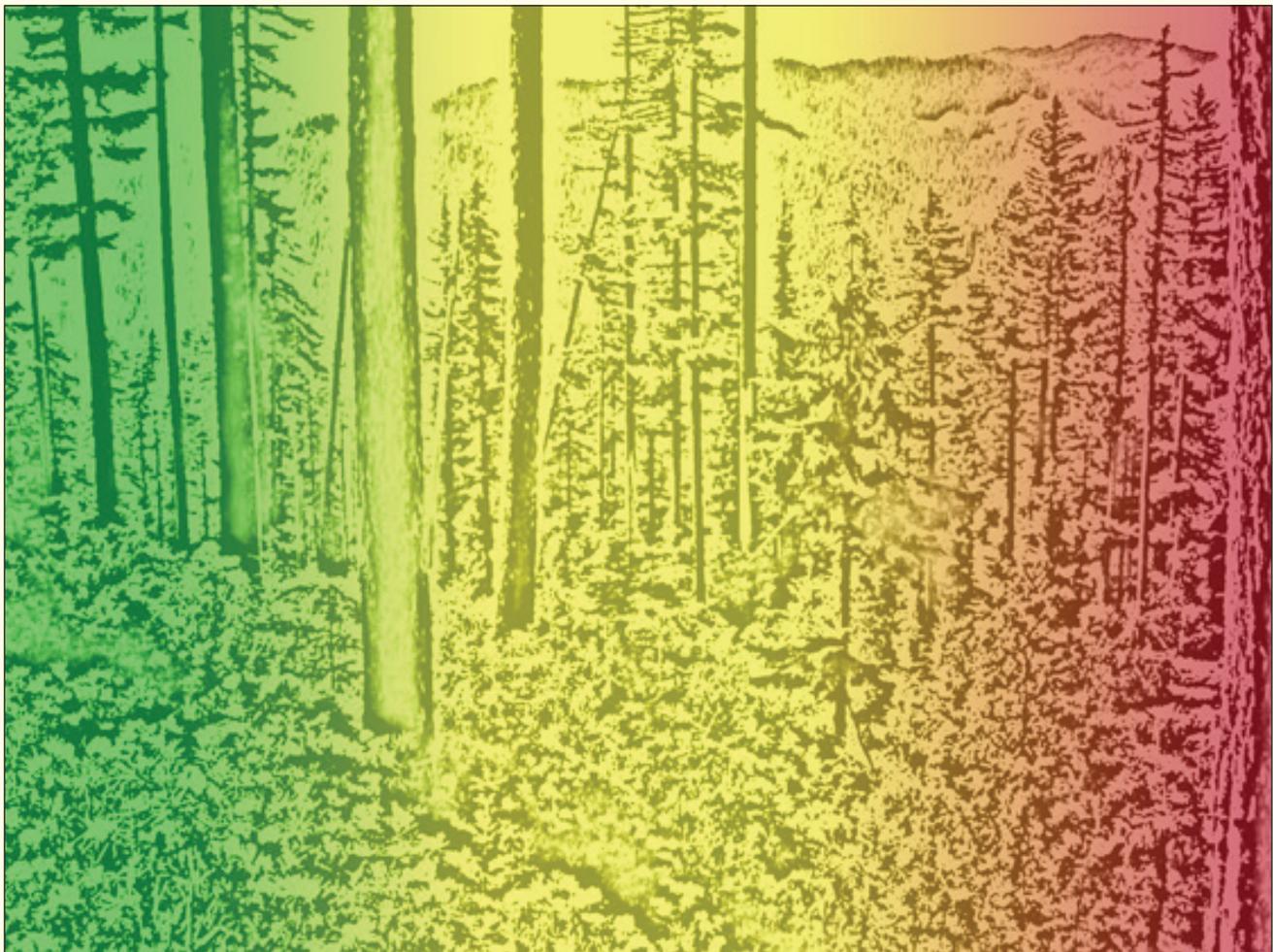
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# Effects of Climatic Variability and Change on Forest Ecosystems: A Comprehensive Science Synthesis for the U.S. Forest Sector



## Hawaii and the U.S.-Affiliated Pacific Islands

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Hawaii and the U.S.-affiliated Pacific islands, including Guam, American Samoa, Commonwealth of Northern Mariana Islands, Federated States of Micronesia, Republic of Palau, and the Marshall Islands (fig. A1-3), contain a high diversity of flora, fauna, ecosystems, geographies, and cultures, with climates ranging from lowland tropical to alpine desert. Forest ecosystems range from equatorial mangrove swamps to subalpine dry forests on high islands, with most other forest life zones between. As a result, associated climate change effects and potential management strategies vary across the region (Mimura et al. 2007). The vulnerability of Pacific islands is caused by the (1) fast rate at which climate change is occurring; (2) diversity of climate-related threats and drivers of change (sea level rise, precipitation changes, invasive species); (3) low financial, technological, and human resource capacities to adapt to or mitigate projected effects; (4) pressing economic concerns affecting island communities; and (5) uncertainty about the relevance of large-scale projections for local scales. However, island societies may be somewhat resilient to climate change, because cultures are based on traditional knowledge, tools, and institutions that have allowed small island communities to persist during historical periods of biosocial change. Resilience is also provided by strong, locally based land and shore ownerships, subsistence economies, opportunities for human migration, and tight linkages among decisionmakers, state-level managers, and landowners (Barnett 2001, Mimura et al. 2007).

The distribution and persistence of different forest species are largely determined by temperature and precipitation and for coastal forests, sea level rise. Based on known historical climate-vegetation relationships, many forests are expected to experience significant changes in distribution and abundance by the end of the 21<sup>st</sup> century. Over the past 30 years, air temperature for mid-elevation ecosystems in

Hawaii increased by 0.3 °C per decade, exceeding the global average rate (Giambelluca et al. 2008a). Streamflow decreased by 10 percent during the period 1973 to 2002 compared to 1913 to 1972 (Oki 2004), which is similar to what is suggested by simulation modeling for a warmer climate (Safeeq and Fares 2011). Preliminary climatic downscaling for the Hawaiian Islands projects that continued warming and drying will be coupled with more intense rain events separated by more dry days (Chu and Chen 2005, Chu et al. 2010, Norton et al. 2011). This appears to be accurate for the central and western Pacific (Mimura et al. 2007), and at least for Hawaii, climatic forecasting suggests that this pattern will be more pronounced in drier areas of the state.

The direct effects of climate change on forests will be variable and strongly dependent on interactions with other disturbances, especially novel fire regimes that are expanding into new areas because of invasion by fire-prone exotic grass and shrub species (fig. A1-4), such as fountain grass (*Cenchrus setaceus* [Forssk.] Morrone) and common gorse (*Ulex europaeus* L.) in Hawaii and guinea grass (*Urochloa maxima* [Jacq.] R.D. Webster) across the region (D'Antonio and Vitousek 1992). Combined with warmer and drier conditions, these invasions have the potential to alter or even eliminate native forests through conversion of forested systems to open, exotic-dominated grass and shrub lands.

In wet forests, invasive plants can alter hydrologic processes by increasing water use by vegetation (Cavaleri and Sack 2010), and these effects may be more severe under warmer or drier conditions (Giambelluca et al. 2008b). Because invasive species have invaded most native-dominated ecosystems (Asner et al. 2005, 2008), anticipated direct (higher evapotranspiration) and indirect (increased competitive advantage of high water use plants) effects of climate change will modify streamflows and populations of stream organisms. Higher temperature will facilitate expansion of pathogens into cooler, high-elevation areas and potentially reduce native bird populations of Hawaii (Benning et al. 2002).

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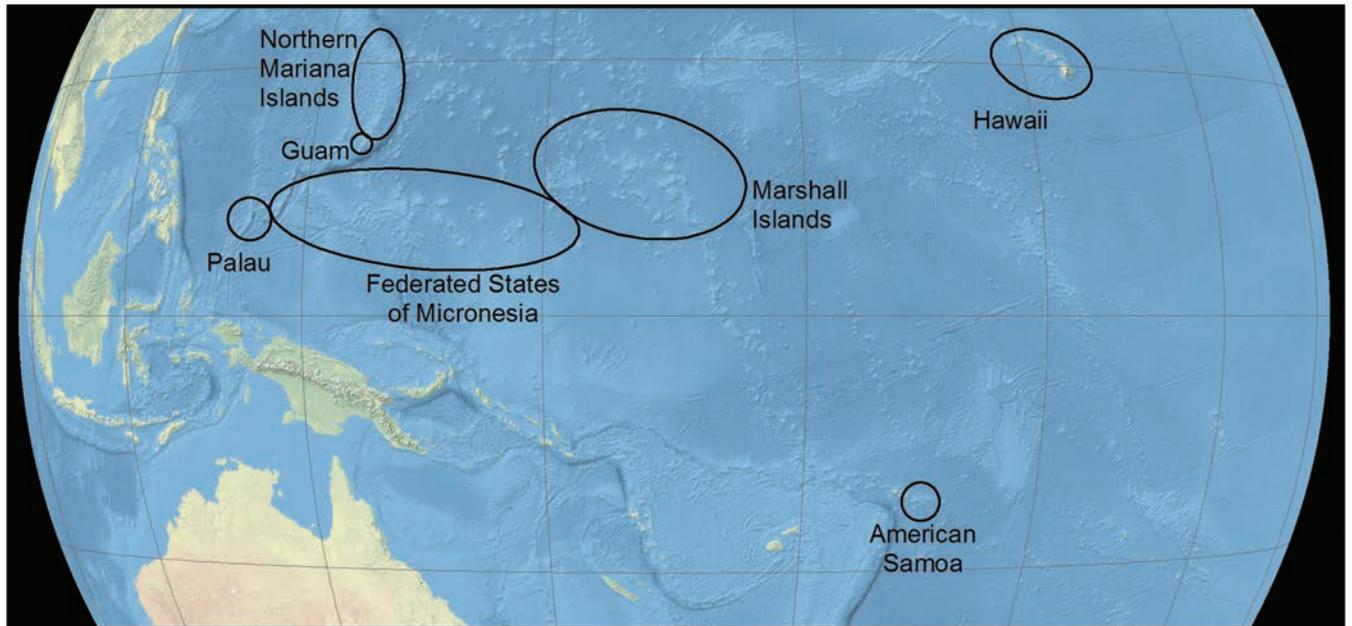


Figure A1-3—Hawaii and the U.S.-affiliated Pacific islands.



Figure A1-4—In Hawaii's high-elevation forests (shown here) and in forests across the Pacific, projected warming and drying will increase invasive plants such as fire-prone grasses, resulting in novel fire regimes and conversion of native forests to exotic grasslands. For areas already affected in this way, climate change will increase the frequency and in some cases intensity of wildfire.

Although Hawaii's Mauna Loa Observatory has been documenting the steady rise in atmospheric carbon dioxide ( $\text{CO}_2$ ), the direct effects of elevated  $\text{CO}_2$  in forests of the region have not been examined. However, most forests have at least some stimulatory effects from  $\text{CO}_2$  (Norby et al. 2005), especially in younger, faster-growing species. Therefore, the effects of climate on fire regimes and streamflow described above may be accentuated by rising  $\text{CO}_2$  through increased fuel accumulation and increased competitiveness of invasive species; higher water use across the landscape may be partially offset by higher water use efficiency in some species. For strand, mangrove, and other coastal forests, anticipated sea level rise for the region (about  $2 \text{ mm} \cdot \text{yr}^{-1}$ ) (Mimura et al. 2007) will have moderate (initial or enhanced inundation with expansion to higher elevation) to very large (extirpation of forest species in the absence of upland refugia) effects on the distribution and persistence of these systems. Enhanced storm activity and intensity in the region during some large-scale climatic events (e.g., El Niño Southern Oscillation) will enhance the effects of storm surges on these coastal systems and increase salt water intrusions into the freshwater lens that human and natural systems require for existence (Mimura et al. 2007). A combination of sea level rise and

increased frequency and severity of storm surges could result in extensive loss of forest habitat in low-lying islands.

Mimura et al. (2007) suggest high to moderately high confidence for anticipated diverse effects of climate change on island ecosystems (table A1-1). These effects will extend across federal, state, tribal, and private lands, the most vulnerable being coastal systems and human communities. Sea level rise, apparent trajectories for storm intensity and frequency in the region, and warming and drying trends (for Hawaii) are based on robust measurements that suggest high confidence in projected ecological changes. Vulnerabilities and risks are most relevant in coastal zone forests, but all

forests of the region are at greater risk of degradation from secondary drivers of change, especially fire, invasive species, insects, and pathogens.

Island systems of the Pacific are home to some of the most intact traditional cultures on earth and communities that generally are strongly linked to forest resources. Sea level rise, increased storm frequency and intensity, and more severe droughts will reduce the habitability of atolls, representing a major potential impact in Pacific island countries (Barnett and Adger 2003). For low-lying islands of the Pacific, enhanced storm activity and severity and sea level rise will cause the relocation of entire communities and even nations; the first climate refugees have already had to relocate from homelands in the region (Mimura et al. 2007). Climate-driven reductions in coastal forest area and functionality will increase population pressures on already limited natural resources, and the combination of inundation and enhanced storm damage will damage fragile economies (Mimura et al. 2007). For high islands, warming and drying in combination with expanded cover of invasive species, and in some cases increased fire frequency and severity, will alter the hydrological function of forested watersheds, with cascading effects on ground-water recharge as well as downstream agriculture, urban development, and tourism (Mimura et al. 2007).

Few options are available for managing climate-change effects on Pacific island ecosystems. For some very low-lying islands and island systems, such as the Marshall Islands where much of the land mass is below anticipated future sea levels, climate change will reduce fresh water supply and community viability. When fresh water becomes contaminated with salt water, the options for persisting in a location are logistically challenging and often unsustainable. For higher islands, adaptation practices include shoreline stabilization through tree planting, reduced tree harvest, facilitated upward or inward migration of forest species, and shoreline development planning (Mimura 1999). Because many Pacific island lands are owned and managed traditionally, adaptation and mitigation can be enhanced at the community level through education and outreach focused on coastal management and protection, mitigation of sea level rise, forest watershed protection, and restoration actions.

**Table A1-1—Potential climate change related risks, and confidence in projections**

| Risk   | Confidence level |
|--|------------------|
| Small islands have characteristics that make them especially vulnerable to the effects of climate change, sea level rise, and extreme events.  | Very high        |
| Sea level rise is expected to exacerbate inundation, storm surges, erosion, and other coastal hazards, thus threatening infrastructure, settlements, and facilities that support the livelihood of island communities. | Very high        |
| Strong evidence exists that under most climate change scenarios, water resources in small islands will be seriously compromised.   | Very high        |
| On some islands, especially those at higher latitudes, warming has already led to the replacement of some local plant species.   | High             |
| It is very likely that subsistence and commercial agriculture on small islands will be adversely affected by climate change.   | High             |
| Changes in tropical cyclone tracks are closely associated with the El Niño Southern Oscillation, so warming will increase the risk of more persistent and severe tropical cyclones.                                    | Moderate         |

Source: Mimura et al. 2007.

However, cost-effective prescriptions and examples of effective adaptation strategies are rare.

Several options for managing climate-change effects exist in Hawaii, because adequate financial resources and infrastructure are available. Hawaiian ecological relationships differ from those on other islands; for example, mangrove forests serve important shoreline conservation functions in the U.S.-affiliated Pacific islands, but mangrove species are not native to Hawaii and are considered problematic invasives. Land ownership in Hawaii is complex, requiring management for shoreline stabilization to rely on diverse native plant species and institutional partnerships. Because Hawaii has significant topographic relief, as well as moderately sophisticated management infrastructure, anticipatory planning and facilitation of inward species migration is already being practiced in some coastal wetlands.

For the majority of Hawaii's forest systems, sea level rise and storm surges are minor threats. Rather, key threats to native forest plant biodiversity include climate-driven acceleration of invasive species, resulting in displacement of native vegetation and in novel fire disturbance. This creates the potential for long-term conversion of native forests to grass and shrub lands dominated by invasive species. The spread of invasive species can be slowed by multifaceted management strategies (biocontrol, physical and chemical control) and restoration of areas with fire-prone invasives (green break planting, native species planting, physical and chemical control of weed species). To this end, management prescriptions for simultaneously addressing conservation objectives and climate change effects are being addressed by the Hawaii Department of Land and Natural Resources

Watershed Initiative, U.S. Fish and Wildlife Service (USFWS) Pacific Island Climate Change Cooperative, Hawaii Restoration and Conservation Initiative, and Hawaii Conservation Alliance Effective Conservation Program, as well as individual climate change management plans (e.g., USFWS Hakalau Forest National Wildlife Refuge Comprehensive Conservation Plan).

The region has lacked resources and expertise for conducting the research required to comprehensively manage climate change threats; research needs are particularly acute for the U.S.-affiliated Pacific islands. Throughout the region, research is needed to identify the thresholds beyond which social-ecological systems in atolls will be permanently compromised, and the contributions of resource management, behavior, and biophysical factors to pushing systems across these thresholds (Barnett and Adger 2003). Stress complexes in forest systems affect thresholds; especially important are interactions among invasive species, altered fire regimes, insects, and pathogens. Silvicultural research is needed to understand how to treat extensive forest areas for invasive species that appear to use more water than native systems. Effective biocontrol agents are also needed to reduce the most damaging invasive species affecting regional forests. Expanded research in fire science (fire history, fire behavior, fuel characterization) would improve fuel maps and understanding about fire ecology and human dimensions of wildfire. Conservation genetics research would improve understanding of genotypic plasticity and diversity within species, restoration needs and adaptation potential, pathogen resistance in a changing climate, and locally relevant restoration practices that use genotypes and species suitable for future climate.

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